An S/X Compatible VGOS System for the AuScope Array

Jamie McCallum [1], Lucia McCallum [1]

Abstract Work is underway of upgrading the AuScope VLBI Array to VGOS. This is done by replacing the current S/X legacy observing chain with the new VGOS receivers on the existing telescopes. As of now, the conversion to VGOS will mean that the AuScope telescopes cannot contribute to the legacy VLBI, leaving a major gap in the global network. In this contribution we report on our efforts to support legacy S/X VLBI using the new VGOS receiver at the Hobart 12-m telescope. Despite some existing problems with the new back-ends as well as in antenna sensitivity, in principle the legacy observing mode can be covered. We report on a few test experiments, where data collected with the VGOS receiver at Hobart was successfully correlated and processed, revealing promising results. Details are given on the observing setup, the adopted processing chain and first results. Following those initial tests, a more extensive test series, the AUM (Australian mixed-mode sessions), was initiated. Some details about this program are provided.

Keywords AuScope VLBI Array, VGOS, mixed-mode operations, AUM sessions, AUSTRALs

1 Introduction

The AuScope VLBI array [1] consists of three 12-m telescopes, which were built as a dedicated geodetic facility. Compared to current VGOS specifications, the AuScope telescopes are of a slow type, with slewing speeds of fives respectively 1.5 deg/s in azimuth and elevation. The telescopes in Hobart (Hb), Katherine (Ke), and Yarragadee (Yg) have been operating with S/X receivers using recording modes of up to 1 Gbps since 2012. Since 2014, the telescopes have been regularly participating in global and regional IVS sessions, producing one of the most dense time series of VLBI telescopes.

1.1 VGOS Upgrade

While the AuScope VLBI array had already originally been designed for VGOS, the actual receiver upgrade began in 2015. Starting in Hobart, a prototype wideband feed was installed, tested, and improved with the final version of the feed installed in mid-2017. The wideband receiver was designed and built by Callisto, using Stirling cycle cooling. It is equipped with the QRFH feed.

The new VGOS system, which is planned to be installed at all three sites, has evolved to a three frequency band system using a DBBC3 and Flexbuff for the back-end. As illustrated in Figure 1, signals above 3 GHz are sent through a high-pass filter and then via the RF over fiber (RFoF) link to the control room. The frequencies below 3 GHz are mixed with a 1,900-MHz local oscillator signal and sent via the old coax connection.

In the control room, the VGOS signal is split and, using 4-GHz filters, can be input into the DBBC3. Our DBBC3s have six inputs which will be used for three frequency bands at dual polarization. Using the DDC mode, this allows for full VGOS compatibility. In Figure 2, the three overlapping 4-GHz-wide bands are shown.

1. University of Tasmania, Australia

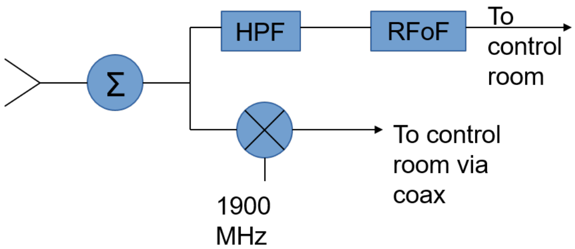

Fig. 1 Signal chain of the new VGOS system installed at Hobart. While the VGOS signals are sent through a high-pass filter (HPF) and are transported at sky frequencies via a fiber connection (RFoF) to the control room, signals below 3 GHz are down-mixed and sent via the old coax cable to the control room.

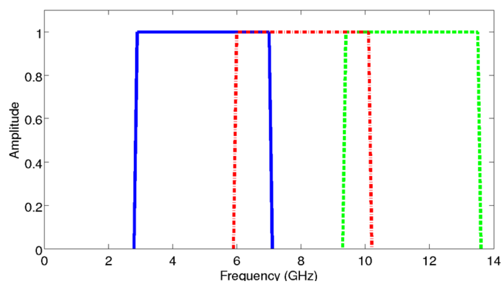

Fig. 2 For AuScope VGOS, we use three input frequencies at 4 GHz into the DBBC3. Using the DDC mode, this allows for full VGOS compatibility.

1.2 One or the Other

Contrary to most other VGOS stations, where new telescopes are built at existing IVS sites, in the case of AuScope the VGOS telescopes will replace the legacy ones. This means that legacy and VGOS operations cannot be done at the same time. Moreover, the implementation itself as well as the necessary testing of the new VGOS chain causes significant down-times of the Australian stations, as shown in Figure 3 for Hb.

The either-or situation puts us in a similar position as Ishioka. With global VGOS operations just taking off (at a current cadence of 2–4 weeks, with geodetic results pending), the question to be asked is when is the right time to upgrade the remaining two telescopes (Ke and Yg). In particular, since as soon as we start this upgrade, nearly the whole Australian continent will disappear from the legacy operations. This leaves a considerable gap in the global network and will without doubt negatively impact the geodetic products of VLBI. The core mandate of the AuScope VLBI network is to contribute to global geodesy and positioning, so how will this mission be served best?

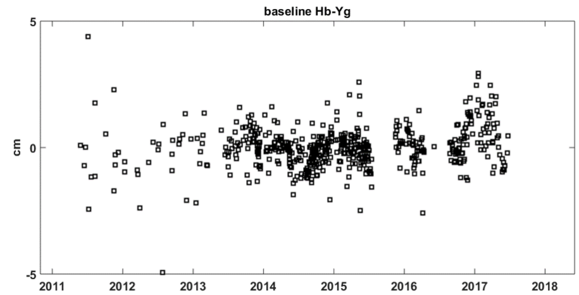

Fig. 3 Starting in 2014, the Hb–Yg baseline used to be one of the most dense baseline time series in VLBI. Multiple tests of the VGOS prototype receiver in 2015 and 2016 as well as the final installation in 2017 cause significant interruptions. Data source: CCIVS.

2 Idea

Our idea to overcome the issue of too much down-times in the transitioning phase are mixed-mode operations. This means, trying to operate the new VGOS receivers in legacy mode.

Are those two systems compatible?

- **Frequency coverage**
  The nominal operating range of the QRFH feed is approx. 2–14 GHz. Despite the usual problem of severe RFI in Hobart—which make local Ho–Hb tests impossible—sensitivity in S-band appears reasonable. The legacy X-band is covered by our 6–10 GHz filter and we achieve reliable fringes in the Ho-Hb baseline. For recording X-band, we only need two (for dual-polarization) inputs for the DBBC3.[1]
- **Polarization**
  While in legacy VLBI we typically use the right-hand-circularly polarized signal (RCP), the VGOS signal comes in two linear polarizations. Hence, one needs to handle the cross-polarization products to get full sensitivity or take a $\sqrt{2}$ loss in sensitivity.
- **S-band signal**
  In our system, the S-band signal is down-converted after the LNA and sent over the coax, while the

[1] This enabled us to test the mixed mode despite the fact that not all six DBBC3 inputs were fully functional at that time.

3–14 GHz signal travels over the fiber connection to the control room. If we want to use and combine both frequencies, we have to take the possibility of different and varying cable delays into account.

3 Test Observations

In May 2018, a few tests of this mixed-mode observations were done. AUSX01 ran over a weekend, using a simple automated schedule, cycling through a list of strong sources with Hb, Ke, and Yg. Ke and Yg used the 1-Gbps AUSTRAL mode [2], with 16x16 MHz channels and S-band restricted to 2.2–2.3 GHz. Hb recorded three VDIF streams using 32-MHz channels. The X-band was recorded through the DBBC3 and the S-band through a DBBC2 using the DDC mode with v105E firmware. Due to a lack of automated scripts, the VEX entries for Hb were created by hand. The observations themselves were steered through the FS plus some additional scripts.

The correlation was performed in one pass, using zoom bands for Hb. The subsequent fringe fitting was done in Fourfit. Figures 4 and 5 show the results of the fringe fitting for S- and X-band, respectively.

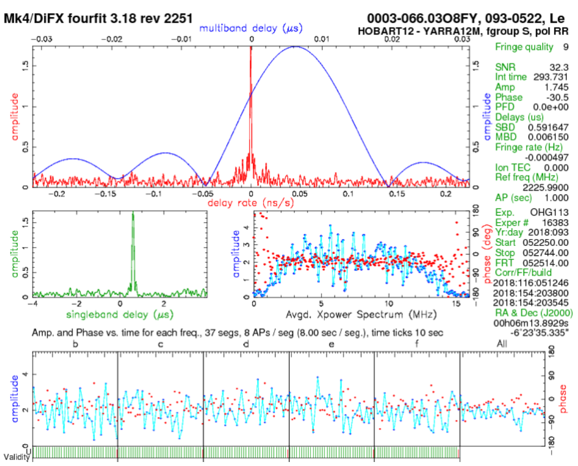

Fig. 4 Fourfit output of AUSX01 for S-band on the Hb–Yg baseline. An SNR of 32 was achieved on a five-minute scan of 093-0522.

We achieved good fringes in both bands and all polarization products. As a comment, for AIPS compatibility the X and Y polarizations at Hb are labelled as R and L. A manual phase calibration correction was applied to each polarization separately.

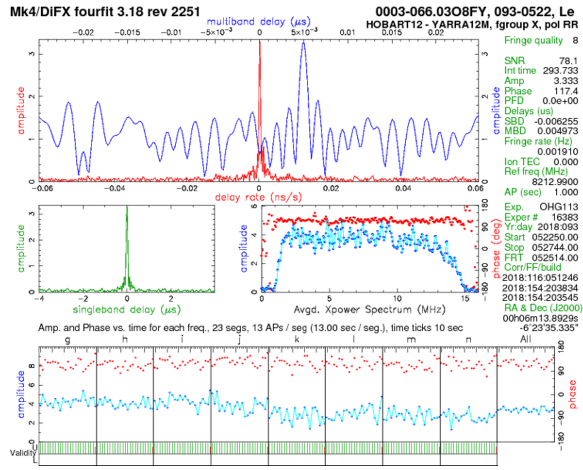

Fig. 5 Fourfit output of AUSX01 for X-band on the Hb–Yg baseline. An SNR of 78 was achieved on a five-minute scan of 093-0522.

In a next step, the different polarization products were then combined in Fourfit using XR + YR with the results further compiled into a database for analysis in NuSolve. Due to the different signal paths for the S- and X-band signal at Hobart (as mentioned above), we found a large (approximately 0.5 μas) offset between the two bands. While it would be possible to remove such offset as an a priori delay offset in the fringe fitting step, in this test we let it soak up in the clock model. Besides this, further inspection of the results did not reveal any obvious deficiencies.

In a second test, Hb12 *shadowed* the last half of the r1840 schedule. Again, we recorded 32-MHz channels and used zoom bands in correlation. Due to a hardware limitation in the DBBC2, no S-band channels above 2.3 GHz were observed. If those are then absent in the VEX file, this caused difficulties in the channel labelling in difx2mark4. In order to resolve this and ensure consistent labelling (e.g., a-f for S-band and n-g for X-band), *fake* channels had to be added in the VEX file.

In a final test, Hb12 was scheduled in AUA044 as a tag-along station. This time the new DBBC3 DDC_L firmware was used, allowing to observe matching 16-MHz channels at X-band. As previously, S-band was recorded using the DBBC2 in DDC mode. Unfortunately, there were power failures just before and during the experiment and a patching error for the S-band data. While X-band fringes were found, S-band data was not successful. However, this test was useful in confirming a working DDC_L mode, which will avoid the issue of unnecessary excess data in the future.

4 Summary

The either VGOS or legacy situation for the AuScope VLBI array poses a significant risk of maintaining a good geodetic measurement history. Establishing a working mixed operation mode was identified as a solution to this situation.

In this contribution we describe a few tests of S/X compatibility that were performed using the new VGOS receiver and signal chain installed at Hobart. We found that the correlation of a single station with a linear polarized feed against the legacy RCP stations is straightforward. The fringe-fitting in this case seems to yield stable results.

5 Outlook

While the results presented above are motivating, we are aware that further, more detailed investigations will be necessary before a mixed-mode station could for example be added into an R1/R4 session in order to maintain good global results.

For this reason, the AUM sessions are currently being conducted. A series of ten 24-hour experiments have been scheduled from July through September 2018 (see Table 1). The observation setup is similar to AUA044, using Ke and Yg in legacy and Hb in VGOS mode.

Table 1 AUM session schedule.

sess name	date	time	network	scheduler	correlation
AUM001	Tue Jul 31	17:30	HbKeYg	VIEN	UTAS
AUM002	Wed Aug 01	18:00	HbKeYg	VIEN	UTAS
AUM003	Wed Aug 08	18:00	HbKeYg	VIEN	UTAS
AUM004	Wed Aug 15	18:00	HbKeYg	VIEN	UTAS
AUM005	Sat Aug 18	16:00	HbKeYg	VIEN	UTAS
AUM006	Sun Aug 19	16:30	HbKeYg	VIEN	UTAS
AUM007	Sat Aug 31	19:00	HbKeYg	VIEN	UTAS
AUM008	Wed Sep 12	18:00	HbKeYg	VIEN	UTAS
AUM009	Wed Sep 19	18:00	HbKeYg	VIEN	UTAS
AUM010	Mon Sep 24	16:30	HbKeYg	VIEN	UTAS

First data of these experiments has arrived in Hobart and correlation is underway. These experiments are further a great motivation to improve the scheduling and implementation of VGOS observations as well as improving the sensitivity and reliability of the new VGOS system in Hobart. Hopefully we can report on successful results soon.

Besides that, we are also carrying out tests to improve the performance of the receiver system and we intend to use the AUM series to provide a cross-check on the results.

References

1. J. Lovell et al., "The AuScope geodetic VLBI array", Journal of Geodesy, 87:527-538, doi:10.1007/s00190-013-0626-3, 2013.
2. L. Plank et al., "The AUSTRAL observing program", Journal of Geodesy, doi:10.1007/s00190-016-0949-y, 2016.